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Elimination of Heat-Shielding for Geothermal Tools Operating Up To 300 Degrees Celsius

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ABSTRACT

This report focuses Sandia National Laboratories' effort to create high-temperature logging tools for geothermal applications NOT requiring heat-shielding. Tool electronics can operate up to 300°C with a few limiting components operating to 250°C. Second generation electronics are needed to increase measurement accuracy and extend the operating range to 300° and then 350°C are identified. Custom development of high-temperature batteries and assembling techniques are touched on. Outcomes of this work are discussed and new directions for developing high-temperature industry are suggested.

1. INTRODCTION

In the past 30 years, electronics have been qualified for operating within three temperature ranges: commercial, industrial and military. New higher temperature applications for commercial and military aircraft have pushed for the development of new high-temperature electronics, creating a new 225°C standard, [1]. Table 1 provides the fore mentioned temperature ranges in degrees Celsius and Fahrenheit.

These new high-temperature components are based primarily on Silicon-On-Insulator (SOI) technology. Figure 1, shows a CMOS transistor pair constructed using common bulk silicon and SOI. The buried oxide layer, in SOI, forms a non-conducting layer where the N-substrate common to lower temperature electronics is a semi-conductor material. This buried oxide layer reduces leakage current by a factor approaching 100X, [1].

Obviously, the benefit of this new technology is the possibility of displacing (or reducing) the Dewar (heat-shield). At present, the Dewar flask is one of the highest cost components in any geothermal logging tool, [2]. If high-temperature electronics can displace the Dewar flask there are significant benefits. Following is a list of benefits of Dewarless and Dewared tools.

Advantages of HT electronics over Dewared tools.

- Unlimited time downhole where the Dewar flask provides only 8-12 hrs in most applications.
- Reduced tool outer dimension, where the flask adds a 50-100 mm to the outer diameter.
- Reduced tool cost by both reducing possible tool damage downhole from overheating and replacing the expensive Dewar flask.

Advantages of Dewaring tools

- Broader range of electronic components to choose from when designing a logging tool.
- Normally, higher accuracy measurements because of greater component selection and reduced operating temperature range.

Work at Sandia National Laboratories is to demonstrate designs for operating up to 300°C and to encourage the continued development of electronic devices to regain measurement accuracy at those elevated temperatures. The goal of this report is to relate Sandia on-going activities and discuss high-temperature issues.

For the purposes of this discussion, a very simple block diagram showing the needed elements in most downhole instruments is shown in Figure 2.

Working from the bottom of Figure 2 and up. First the sensors measure wellbore information and convert it to a voltage or electrical frequency. These changes in voltage or frequency are then conditioned by analog circuits in a form acceptable for conversion from analog to digital. Once in digital form, the microprocessor can either store the result in memory or transmit it to the surface.

All electronic circuits need power, normally DC voltage and current. Power can either be sent down via an e-line or self-contained within the tool by use of high-temperature batteries.

2. SENSORS

High-temperature sensors can be broken down into three categories; readily available, soon to be available, may never be available.

2.1Readily Available: Many geothermal sensors are already available for high-temperature applications. This is true because these sensors were already making direct contact with the wellbore environment in conventional logging tools. Sensors as temperature, acoustic, strain, and spinner can be found as off the shelf items.

2.2 Soon to be Available: Some sensors, like pressure sensors, were housed inside the Dewar flask with only a small pressure port leading to the wellbore. For a Dewarless pressure tool, new pressure sensors will be required. At present, we at Sandia are aware of several companies working on high-accuracy, high-temperature pressure sensors.

Other sensors didn't require wellbore exposure. For example, the measure of magnetic fields and/or vibration could be done inside the Dewared housing. There exists reasonable evidence that magnetometers and accelerometers can be produced for 300°C. Here, the use of high-temperature materials can lead to new high-temperature sensors based on older technology.

2.3 May Never be Available: Still, other sensors like Sodium Iodide [NaI(TI)] used for gamma spectroscopy will require a break through in technology in order to operate at 300°C.

3. ANALOG CIRCUITS

In the resent past, the stumbling block for high-temperature instrumentation (>200°C) has normally been the lack of analog devices. Analog devices are used to amplify, filter, buffer or otherwise interface sensor signals to digital converters. Any inaccuracies in the analog device can ripple though as sensor error. By their very nature, analog integrated circuits are sensitive to the leakage currents caused by elevated temperatures. Here is where SOI is having the largest impact. As such, testing of Honeywell's HTMOS™ quad operational amplifier (HT1104) shows real promise. Figures 3 and 4 are actual test data taken from SOI operational amplifiers. Although, not enough component testing was done to truly qualify these devices for 300°C operation, the measured results are extremely positive showing useful device performance up to 315°C.

The frequency response is good enough for most sensors such as accelerometers, pressure transducers, low frequency acoustics, and others. The DC offset voltage error is a problem for DC dependent sensors as strain and inclination. In phone conversations with Honeywell's Solid State Electronics Center, which is responsible for this device, second generation devices will soon be available with reduced offset voltages.

Other devices, as linear voltage regulators, have also functioned to very high temperatures, >250°C. Here the limiting factor is the voltage reference. The voltage reference is a common electronic component used not only in voltage regulation but also in converting sensor signals to digital values. At present, there are a number of proposals under review for developing high-accuracy, high-temperature voltage references using wide band-gap semi-conductor materials, as SiC (Silicon-Carbide). These new voltage references will not only improve the operating range of the linear voltage regulators but will increase overall instrumentation measurement accuracy. With this improvement, new high-temperature electronics may provide near room temperature measurement accuracy.

4. DIGITAL CIRCUITS

Advanced CMOS military specification electronic devices often continue to operate as high as 300°C without the added benefit of SOI technology. Even so, SOI digital circuits have the advantage by keeping supply currents considerably lower at elevated temperatures, reducing downhole power requirements. And more importantly, the SOI devices are tested and qualified for high-temperature applications at the factory meaning higher dependability and confidence.

At Sandia, we have tested complete microprocessor designs using SOI microprocessors and memory. Other required digital interface logic came from the advanced CMOS family of electronic devices. [3]

The microprocessor circuit is the basic building block for our new high-temperature logging memory tool. This circuit was tested up to 300°C and above with several hundred operating hours at temperatures between 250-300°C. Future plans are to incorporate all digital logic to SOI by developing an SOI gate array. This gate array will increase functionality and allow memory addressing up to 8M bytes for data storage.

In the fore mentioned microprocessor circuit temperature testing, the digital clock had to be supplied from outside of the test chamber. At present, digital clock technology is limited to ~240°C. This may change soon, as testing is presently underway at Sandia of a new digital clock qualified by the manufacturer for 300°C operation.

5. POWER SOURCES

A downhole tool has two choices for power, wire-line or batteries. Both have concerns at 300°C. High-temperature wire-lines are expensive and have a limited life at temperatures approaching 300°C. Commercially available batteries have a limited operation up to 200°C with the exception of thermal batteries, which only start operating at 300°C and above.

At Sandia, the development of thermal batteries with lower operating temperatures was considered as the best option. The development of high-temperature batteries gives the tool designer the option for a memory tool. Memory tools can be deployed on either slick-line cable or conventional wire-line.

Here our battery development effort is to close the gap between the starting temperature of thermal batteries and that of conventional batteries. Work is ongoing to develop a thermal battery with useful power production below 200°C and above 300°C. To date, battery chemistry has been developed which starts operating at 240°C and continues until 350°C.

6. SANDIA'S FIRST P/T DEWARLESS TOOL

The Sandia Dewarless pressure and temperature tool is presently under going oven testing to 250°C. The on board voltage reference is the limiting factor. This tool is scheduled for its first wellbore deployment on August 17 1999. **{Following our first deployment, we will have comparative data between our Dewared T/P tool and new Dewarless tool to add to this paper for WGC2000. Also, by January 2000, I should also have new data on the SOI Analog-to-Digital 12 bit converter. At present, our Dewarless P/T tool is using a high-temperature Voltage-to-Frequency converter.}**

The tool electronics are mainly composed from Honeywell's HTMOS™ product line. The components are mounted on a custom ceramic board and welded in place.

The first deployment is expected to be within a well operating between 220-250°C. The goal of the test is to monitor well conditions continuously for 48hrs. Additional wells at higher temperature and longer duration will follow in the coming year. Additional test data will be available at the WGC2000 on request.

7. THE FUTURE IS MOVING UP TO 350°C

Silicon-On-Insulator technology is limited to 300°C. This is particularly true for instrumentation quality electronics. As previously stated, there are efforts to improve the performance of a few temperature limiting components. For example, a simple voltage reference (needed in virtually any tool) produced in SOI has stability problems above 250°C. Research to create a stable voltage reference from wide-band gap semiconductor materials is underway.

One of the leading semiconductor material technologies is SiC. SiC devices have been shown to operate above 350°C. SiC has the unique advantage of both high temperature operation and great chemical stability making it a desirable material for micro-machine technology. Thus, future SiC devices may contain electronics and sensors on a single chip.

The fundamental problem with SiC is the cost of production. It is hoped that new SiC components, supplementing SOI for improved performance, will develop new markets for high-temperature wide-band gap materials. These first simple devices will lead the way to greater commercial acceptance of the technology resulting in increased demand and falling costs.

In the future, complete tool designs could be developed using SiC device technology. SiC will enable instrumentation electronics to operate above 350°C.

8. CONCLUSSION

Silicon-On-Insulator (SOI) technology for high-temperature electronics is becoming commercially available. This new technology is pushing the operation temperature of downhole tool electronics to 225°C and higher. Thus, there is a possibility to eliminate the Dewar-flask used on most

Table 1
Temperatures for Various Grades of Electronics

Grade	Operating Range C (F)
Commercial	0 to +70 °C (0 to 158 F)
Industrial	-25 to +85 °C (-13 to 185 F)
Military	-55 to +125 °C (-67 to 257 F)
High-Temperature	-55 to +225 °C (-67 to 437 F)

geothermal tools. The advantages of a Dewarless tool are: slimmer design, unlimited wellbore exposure, and reduced cost.

Work at Sandia National Laboratories has shown that simple data logging tools can be designed for temperatures as high as 300°C however there is a trade off in measurement accuracy. Continuing development of second generation high-temperature wide band-gap (SiC) electronics will improve high-temperature measurement accuracy while eventually extending the operating range of high-temperature electronics to 350°C or more.

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REFERNECES

1 Swenson, Gregg and Ohme, Bruce. (1996). HTMOS™: affordable high temperature product line. trans. Third International High Temperature Electronics Conference (HiTEC). Vol 2,pp 89-94.

2 Normann, Randy A and Guidotti, Ronald A. (1996). A study of the use of high-temperature electronics and batteries to avoid the use of Dewars for geothermal logging. Trans Geothermal Resources Council, Vol 20, pp 509-513

3 Franco, R .J. and Sleefe, G.E. CMOS devices and design methodology for 200°C circuits, trans. Sec. Internationa High Temperature Electronics, June 5-10, 1994

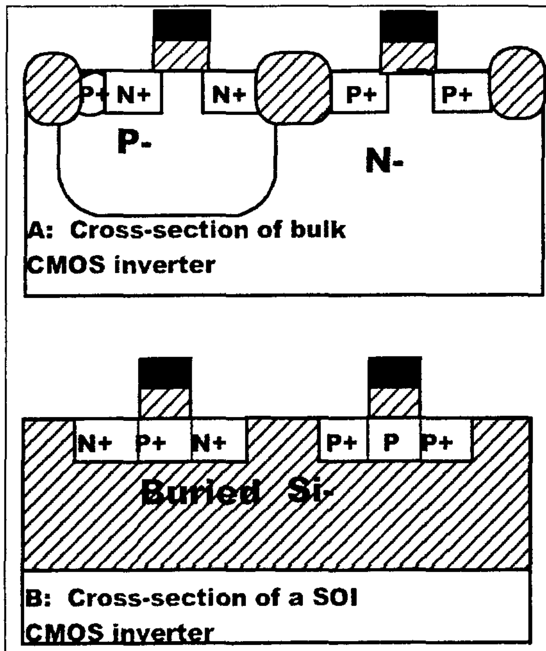

Figure 1. Comparing standard bulk silicon and SOI construction for CMOS. CMOS is a type of digital logic gate made from two transistors. The buried oxide layer of SOI prevents loss of leakage current from the CMOS

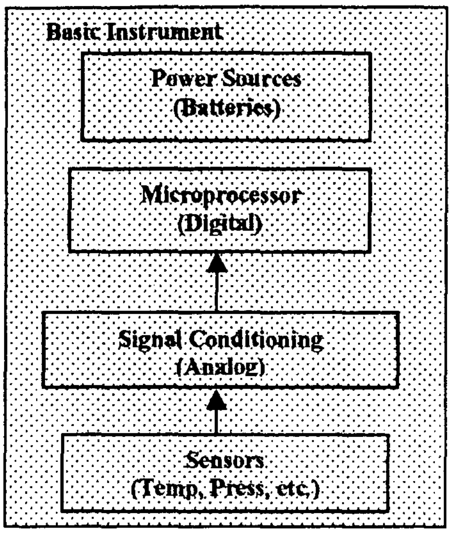

Figure 2. Basic block diagram of a downhole instrument. The sensor information is processed first by analog circuits and then by digital circuits

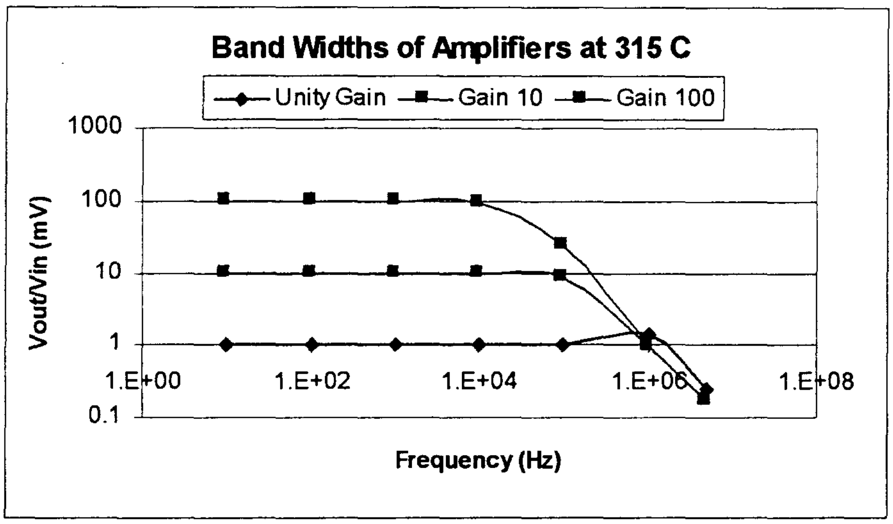

Figure 3. Several operational amplifiers were tested with three different gains, unity, X10, and X100. Not only were these devices functioning well as signal amplifiers at 315°C but the bandwidth is well over 100KHz at unity gain.

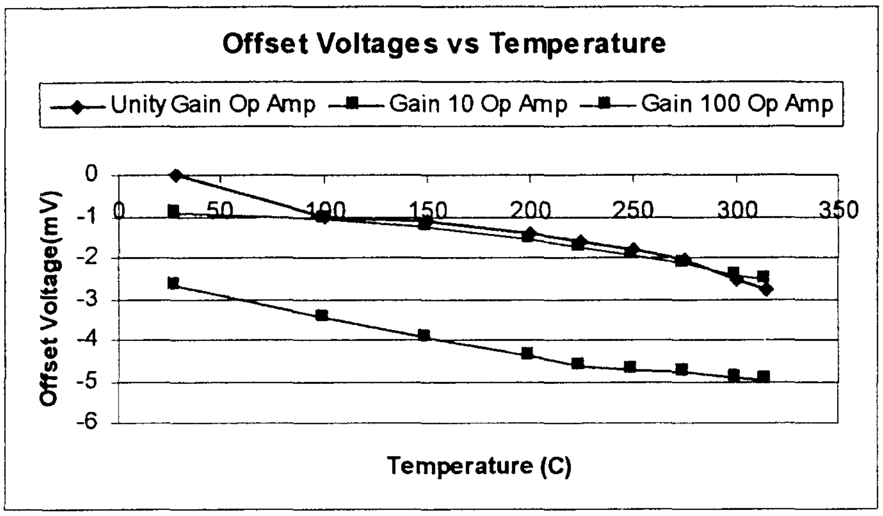

Figure 4. The offset voltage (error voltage with zero input) is seen here as a function of temperature. The manufacture only qualifies the offset voltage up to 225°C.